Title: Relay Satellite Orbit Selection Considerations for Future Robotics Missions to Explore Venus

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Extended Abstract:

Introduction

In recent years, there has been a rebirth of interest in NASA's long term mission of planetary exploration. Following the recent successful Magellan mission to Venus, it now appears appropriate to begin initial consideration of possible robotic missions to Venus. In particular, several concepts for robotic missions to obtain information relevant to the atmosphere and surface of Venus are now under consideration by NASA.

For all of the potential missions currently under consideration, telecommunications is essential for returning gathered scientific data to Earth. Due to the large distance from Venus to Earth (-1.7 AU), communications equipment supporting links between Venus and Earth represents a significant mass, power, and cost burden for any mission clement in the Venus region. With the potential for multiple simultaneous elements at Venus, the costs associated with providing each element a separate communications capability with Earth can become excessive. One way to reduce this burden is to use a Venus orbiting relay satellite (VRS) to relay information between local Venus elements and Barth. With such a relay, individual mission elements need only have communications equipment supporting a link to and from the relay satellite -- at much lower mass, power, and cost than a system capable of communications directly to and from Earth. Additionally, a relay satellite, by collecting data from local Venus elements and then later transmitting the data to Earth, offers the potential for data relay from elements at Venus that are not directl y visible from the Earth. For all of these reasons, the consideration of a Venus orbiting relay satellite providing communications support to multiple missions in the Venus region appears appropriate at this time.

This paper discusses orbit design trades relevant to use of a Venus orbiting relay satellite supporting a variety of potential Venus robotic mission types. The emphasis is on the impact of mission telecommunications requirements on selection of a relay satellite orbit and those characteristics of the relay satellite orbit that can benefit or hinder mission performance for the variety of potential Venus robotic missions now under consideration. The results to be reported in this paper are based on studies performed by the Jet Propulsion Laboratory and Stanford Telecommunications, Inc. under the sponsorship of NASA's Office of Space Communications,

Mission Requirements

The types of missions which are being considered for Venus and for which Earth communications could be enhanced by an orbiting relay satellite include:

- Atmospheric probes for collecting data while descending though the Venus atmosphere; they are not generally expected to survive impact.
- Landers of several varieties for surface studies, having progressively longer lives. Multiple simultaneous landers are desirable for seismic data collection,
- Balloons which would repeatedly descend to the surface, touchdown and return to the upper atmosphere.
- Rovers for surface exploration.

Key Trades

VRS orbit characteristics have a large impact on both connectivity to the mission elements (i.e., h-situ coverage) as well as the quantity of data which can be transmitted from mission elements to the VRS. Trades relative to each of these considerations are outlined below. A key factor that greatly influences both coverage and data quantity trades is the very slow rotation rate of Venus. It takes ~243 days for Venus to rotate once about its axis, causing planet/VRS orbit geometric relationships to remain relatively constant from one (Earth) day to the next, Contrast this situation to the Earth, for which a polar orbiting satellite (such as LandSat) can be assured coverage to the entire planet once every few days (since the Earth rotates beneath the relatively fixed plane of the orbit once per day). No simple solution exists to guarantee data return from every point on Venus over such a short time period. The sections below provide sample in-situ coverage and data quantity analyses relevant to both elliptical and circular Venus orbits. As described below, orbit selection greatly impacts both of these key telecommunications characteristics.

Coverage

A VRS in a circular orbit can provide daily contact to a limited band of users, those some distance on either side of its ground trace. The width and placement of the band or swath of surface coverage is orbit dependent- higher altitude satellites have a wider coverage swath, zero inclination satellites have their swaths centered on the equator. Landers are thus limited in their possible deployment locations by the type of orbit chosen for the relay satellite.

For many of the candidate Venus missions, locations of Venus surface elements maybe restricted to lower latitude regions of Venus, with only limited missions (such as balloons) reaching higher latitudes, Exhibit 1 defines in-situ coverage provided to a variety of circular Venus orbits emphasizing orbits that provide daily coverage to the equatorial regions of Venus. The dashed lines define combinations of VRS altitude and inclination that provide coverage (each day) to all surface points on Venus within a swath of indicated size about the equator of Venus. The solid lines define orbits that provide some coverage to either ±80° or ±90° latitude, If a circular satellite with an altitude of 10,000 km is inclined, that inclination can go as high as -40° and the relay can still provide service to a lander anywhere along the entire equator, as seen by the dashed equator demarcation line. Any satellite with a combination of altitude and inclination which places it above and to the right of the 90° line will be able to see the poles. Relay satellites with the combination of characteristics located to the right and between the equatorial line and the pole line will be able to see both the entire equator and both poles, though there will still be holes in the coverage at middk latitudes.

Exhibit 2 shows a coverage plot of a sample, highly elliptical orbit having a 12 hour period and 600 km periapsis altitude. Placing the line of nodes parallel to the line of apsides allows for complete equatorial coverage for landers with a 15° elevation minimum viewing elevation restriction. Note that the amount of the surface provided coverage varies greatly between apoapsis and periapsis. Thus the eccentricity of the chosen orbit influences the potential lander locations that can be provided communication service.

in-SItul?ataReturn

Exhibit 3 examines in-situ data return for a range of circular orbits. Lander and VRS parameters have been held fixed in the exhibit (fixed transmit power, frequency, antenna choke and sire). The aggregate data return potential for each surface location is plotted. The decrease in the aggregate data return per location per day for higher altitude, longer period relays is a result of the increased communications range. Note that while contact times are greater for higher altitude orbits, the return data rate achieved by a surface element decreases as the square of communications range (all other factors being fixed) resulting in a net decrease in data returned.

For highly elliptical VRS orbits, the situation is somewhat more complex. Duet o the very large variations in surface to VRS range and contact times occurring during the orbit of the. V KS, rate adaptation schemes, adapting the data rate to an optimum value corresponding to local communications conditions, need to be used to optimize the data returned to the VRS. While this adds complexity to the communications packages of both the landers and the VRS, the added complexity needs to be weighed against the increased difficulty of circularizing the VRS orbit.

Exhibit 4 illustrates aggregate data return from surface points to the VRS as a function of surface location over a one day period for an example elliptical VRS orbit. Using rate adaptation to permit the data rate to be raised as the range to the surface is reduced permits significant data quantities to be returned to the VRS by points beneath the VRS periapsis despite their very short contact times (e.g., a few minutes).

Summary

As described above, selection of a VRS orbit has a large impact on overall mission performance for the potential Venus missions now under consideration. Final determination of orbit characteristics for the VRS will depend greatly on the set of Venus missions to be supported, their deployment locations at Venus, and the individual needs of each mission.

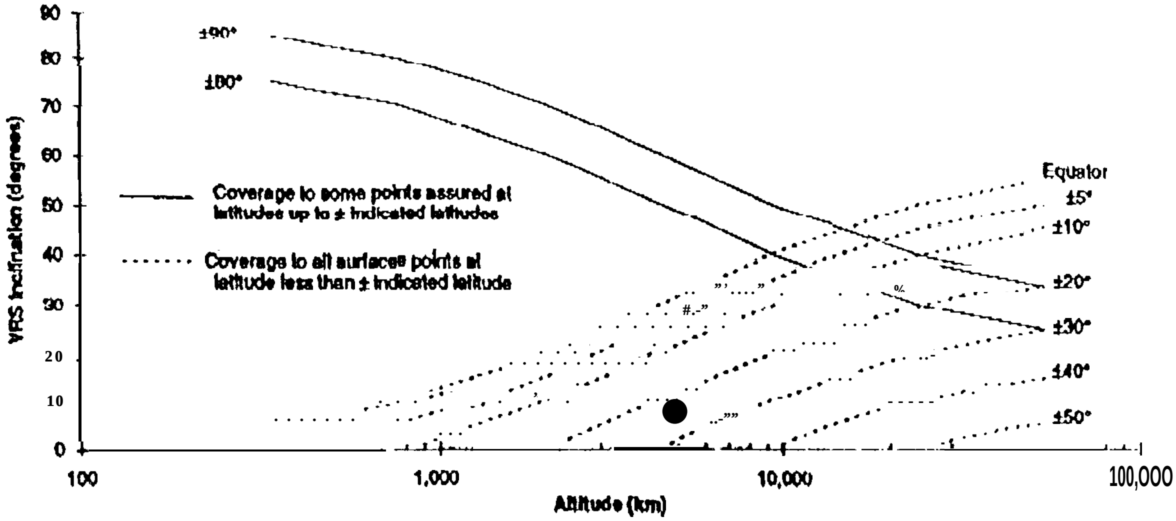

Exhibit 1: Venus Surface Regions Provided Connectivity by Various Circular VRS Orbits

VRS: 600 km Periapsis Altitude, 12 Hr Period
Line of Apsides Parallel to tine of Nodes

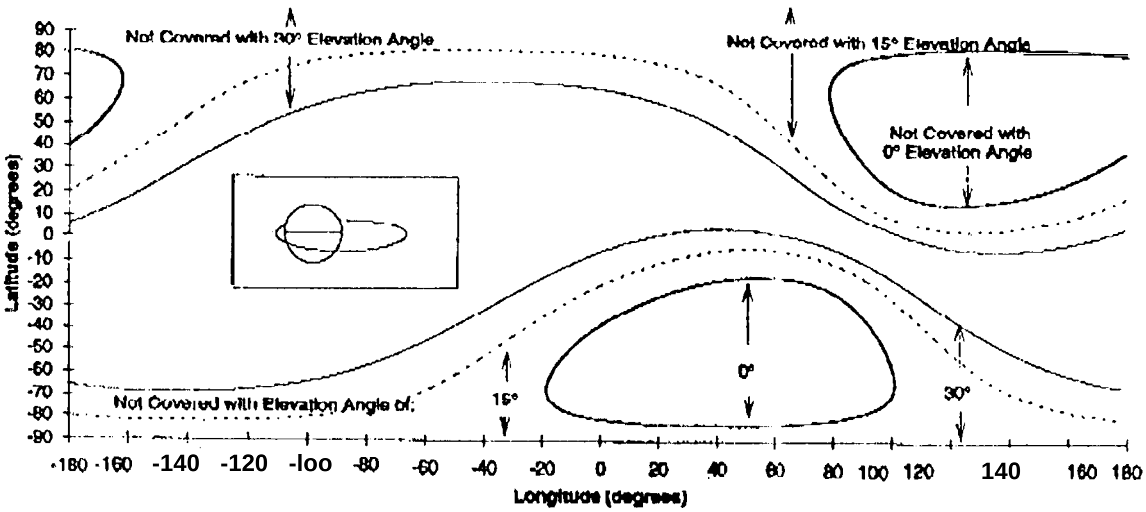

Exhibit 2: Surface Regions Provided Coverage by an Elliptical VRS Orbit at Various Minimum Lander Elevation Angles

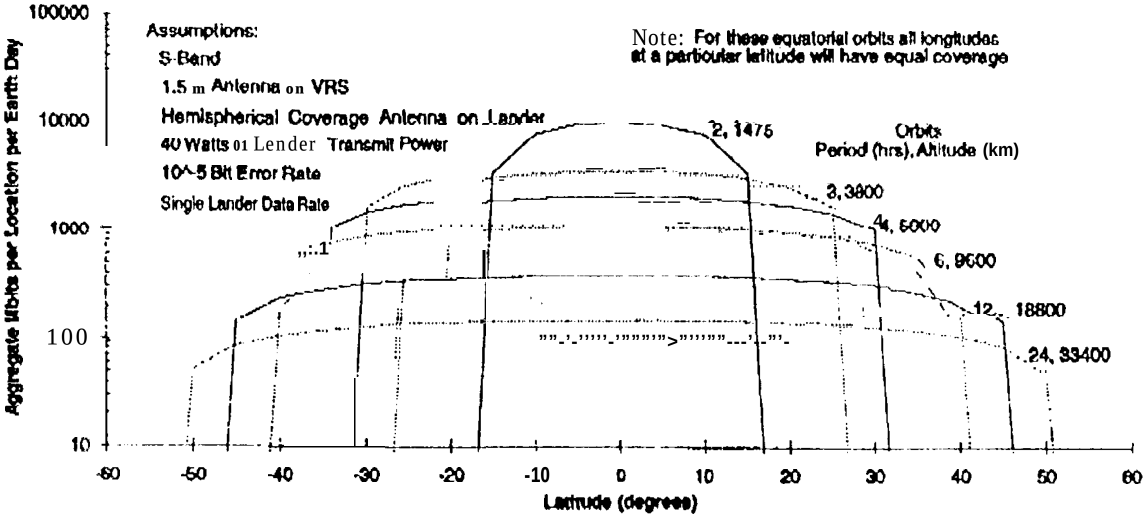

Exhibit 3: In-Situ Return Data Quantity for Various
Circular, Equatorial VRS Orbits and Lander Locations

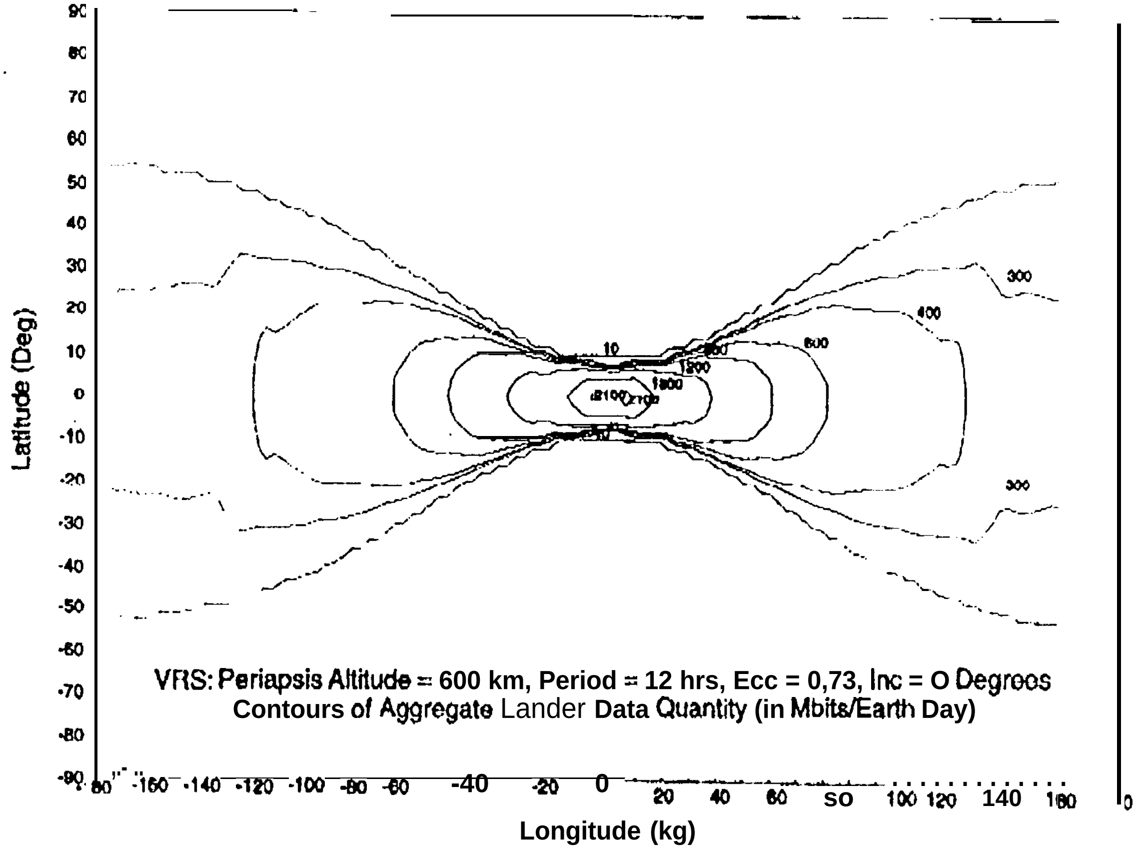

Exhibit 4: In-Situ Surface Data Quantity per Earth Day vs Surface Location for an Elliptical VRS Orbit